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INVESTIGATION OF TEST METHODS,
MATERIAL PROPERTIES, AND PROCESSES
FOR SOLAR CELL ENCAPSULANTS

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ENCAPSULATION TASK OF THE FLAT-PLATE
SOLAR ARRAY PROJECT

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I. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for the Flat-Plate Solar Array project (FSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

During this quarter research work continued on the evaluation of soil resistant surface treatments, the investigation of corrosion protecting coatings for mild steel substrates, the identification of primers for bonding module interfaces, and the continuation of RS/4 accelerated aging of candidate encapsulation compounds.

Soiling test specimens were prepared by treating glass and two candidate outer cover films, Tedlar and Acrylar, with selected coatings based on silicone, acrylic and fluorocarbon chemistries. The specimens have been exposed to outdoor soiling conditions for five months and have been evaluated for loss of short circuit current with a standard cell device. The effectiveness of the treatment is dependant on the type of surface, however the fluorocarbon based silanes have been found to be the most effective treatments in all cases. Untreated Sunadex glass dropped the I_{sc} by 3.0%, but when treated with L-1668 silane showed a loss of only 0.4%.

Mild steel is a readily available and easily worked material that holds the promise of being a cost-effective substrate. Its major deficiency is that of corrosion sensitivity. Experiments are underway to assess the durability and cost effectiveness of coatings for protection of steel. Test specimens were prepared with a variety of films, paints and pottants and then exposed to 35°C Salt Spray (ASTM B-117) and outdoor weathering conditions. The specimens were evaluated for degree of corrosion, delamination and other destructive effects at regular intervals. The salt spray and outdoor results generally correlated well, except for the degree of attack, which was much more severe in the heated salt fog. Untreated control specimens survived three hours under salt spray before extensive corrosion became apparent. The most successful coating identified so far is lamination with an EVA/Scotchpar polyester combination which has endured 2,500 hours of salt spray with no signs of change. Other coatings based on EVA/Zinc chromate and a fluorocarbon based paint have

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survived 2,000 hours with no signs of attack. Candidate coatings are being added continually and all will be exposed until deterioration sets in.

Primers were evaluated for effectiveness in bonding candidate pottants to outer covers, glass and substrate materials. The bond strengths were determined by standard methods and measured in pounds per inch of bond line. Successful primers were also tested after two weeks of water immersion and two hours of boiling water. Good primers have been identified for bonding EVA (9918) to almost all candidate materials and a new primer that is effective with polyester films was identified that gave bonds of 35 psi. Despite the similarity in chemistry, the EMA is much more difficult to bond and, to date, successful results have only been obtained with glass and mild steel. The polyurethane casting syrup has been effectively bonded to Sunadex, Tedlar and Korad but additional work is required on steel and polyester. The butyl acrylate syrup is the most difficult pottant of all to bond and is additionally complicated by its inherently low tensile strength. Bonds to Tedlar and Sunadex glass that survive the water immersion and boiling tests have been achieved however; they are both low in bond strength, and do not exceed 1 to 2 pounds per inch of width.

R/S 4 sunlamp exposure is a widely used industrial method of assessing the relative stability of plastics to the degrading effects of ultraviolet light. The results are useful for the ranking and comparison of the stabilities of polymeric materials and the effectiveness of additives and formulations. The EVA formulation A9918 is performing extremely well and has survived 27,000 hours exposure to date with no significant change in properties. In comparison, the uncompounded resin begins to degrade in about 500 hours. The other pottants are also surviving without change, however they have not yet accumulated the same number of hours. The fully compounded EMA has endured 10,000 hours, and the casting syrups, polyurethane and butyl acrylate, have been exposed for 8,600 and 5,700 hours, respectively. Pigmented back cover films of Tedlar and Scotchpar and outer cover films of transparent Tedlar (100BG30UT) show no signs of deterioration to date. The low cost biaxially oriented acrylic film, Acrylar (3M Corporation) has been exposed to 12,000 hours so far and shows no change in useful properties, except that a 40% decrease in tensile strength (from 24,000 psi to 14,500 psi) occurred

within the first 1,500 hours. This is believed to be due to stress relaxation in the polymer and to have no effect on the final performance and intended use of the film.

II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.70 per peak watt ($\$70/\text{m}^2$) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per m^2 in midday sunlight, the capital cost of the modules may be calculated to be $\$70.00/\text{m}^2$. Out of this cost goal only 20 percent is available for encapsulation due to the high cost of the cells, interconnects and other related components. The encapsulation cost allocation^(a) may then be stated as $\$14.00/\text{m}^2$ which includes all coatings, pottants, and mechanical supports for the solar cells.

Assuming the flat plate collector to be the most efficient design, photovoltaic modules are composed of seven basic construction elements. These elements are (a) outer covers; (b) structural and transparent substrate materials; (c) pottants; (d) substrates; (e) back covers; (f) edge seals and gasket compounds, and (g) primers. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

(a) JPL Document 5101-68

The former cost allocation for encapsulation materials, $\$2.50/\text{m}^2$ ($\$0.25/\text{ft}^2$) in 1975 dollars, or $\$3.50/\text{m}^2$ ($\$0.35/\text{ft}^2$) in 1980 dollars. The current cost allocation of $\$14/\text{m}^2$ is an aggregate allocation for all encapsulation materials including an edge seal and gasket.

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Extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

<u>Construction Elements</u>	<u>Approximate Cost Allocation^(a) (\$/m²)</u>
. Substrate/Superstrate (Load Bearing Component)	7.00
. Pottant	1.75
. Primer	0.50
. Outer Cover	1.50
. Back Cover	1.50
. Edge Seal & Gasket	1.85

(a) Allocation for combination of construction elements: \$14/m².

From the previous work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The following chart shows the materials of current interest and their anticipated functions:

<u>Status of Encapsulation Materials</u>	
1. Surface materials and modification	Under development
2. Top covers (with UV screening property)	
a. Glass	Available
b. Tedlar X00 BG 30 UT	Available (DuPont)
c. X-22417 Acrylic film	Available (3M Corp.)
3. Pottants	
a. Ethylene Vinyl Acetate	Available (Springborn)
b. Ethylene Methyl Acrylate	Available (Springborn)
c. Aliphatic Polyether Urethane	Available (Development Associates)
d. Poly Butyl Acrylate	Available (Springborn)

Status of Encapsulation Materials- Cont.

- | | | |
|----|--|--|
| 4. | Electrical and mechanical spacer | |
| | a. Non-woven glass mats | Available (Crane Co.) |
| 5. | Substrate panels | |
| | a. Hardboard | Available (Masonite,
"Super-Dorlux", Laurel 200,
Ukiah Standard Hardboard) |
| | b. Standboard | Under development (Potlatch
Corporation) |
| | c. Glass-reinforced concrete | Under development
(MB Associates) |
| | d. Mild steel (incl. galvanized
and enameled) | Available |
| 6. | Back covers | |
| | a. Aluminum foils and polymer
laminates | Available |
| | b. Tedlar, Mylar, Korad
(polymer films) | Available (DuPont, Excell, 3M) |
| | c. Pigmented ethylene vinyl
acetate | Available (Springborn) |
| | d. Others | Under development |
| 7. | Gaskets | |
| | a. EPDM (standard or custom
profiles) | Available (Pawling Rubber
Company, others) |
| 8. | Sealants | |
| | a. "Tape" sealants | Available (Tremco, Pecora, 3M) |
| | b. Gunnable sealants | Available (Tremco, 3M, others) |

In addition to materials, two encapsulation processes are being investigated:

- (1) Vacuum bag lamination
- (2) Liquid casting

The suitability of these processes for automation is also being investigated; however, the selection of a process is almost exclusively dependent on the processing properties of the pottant. This interrelationship may have a significant influence on the eventual selection of pottant materials.

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide maximum light transmission to the cell surface and optimize power output.

This report presents the results of the past quarter which has been directed in technical investigations of other areas significant to the selection of low cost construction materials and the operation of photovoltaic modules. The topics of this report include (a) an analysis of data resulting from experiments with soil resistant surface treatments, (b) a continuing investigation of adhesives and primers for durable bonding of module components, (c) experiments with the corrosion protection of mild steel substrate candidate, and (d) continued evaluation of candidate encapsulation materials under accelerated ultraviolet light conditions with the use of the RS/4 sunlamp exposure chamber.

III. SOILING EXPERIMENTS

The performance of photovoltaic modules is adversely affected by surface soiling due to the decrease in the amount of light available to the cells. Generally, the loss in power is linearly proportional to the quantity of soil that has accumulated on the module surface. To minimize performances losses caused by soiling, photovoltaic modules not only should be deployed in low-soiling geographical areas, but also should have surfaces that have a low affinity for soil retention, a maximum susceptibility to natural cleaning by winds, rain, and snow; and should be readily cleanable by simple and inexpensive maintenance techniques. The action of soiling is considered to be a process of particle accumulation; natural removal by wind and snow; and the activation of chemistries that result in adherence to the surface, thus requiring maintenance techniques.

The theoretical aspects of soiling have been addressed recently in documents produced by the Jet Propulsion Laboratory^(a). The basic findings of these studies show that the rate of soil accumulation in the same geographical area is material independent and that rainfall functions as a natural cleaning agent. The effectiveness of rain in cleaning the surface is somewhat material dependant, however, and some surfaces clean much more easily than others.

The overall effects of soiling in a natural environment was measured with a series of pottants and glazing materials that were placed on the roof of Springborn's facilities in Enfield, Connecticut. As may be seen, in the following table, soil accumulation occurred in all cases, with the soft silicone elastomers being the worst.

(a) Cuddihy, E.F., "Encapsulation Materials Status to December 1979" LSA Project Task Report 5101-144, Jet Propulsion Laboratory, Pasadena, CA., January 15, 1980.

Hoffman, A.R., and Maag, C.R., "Airborne Particulate Soiling of Terrestrial Photovoltaic Modules and Cover Materials", Proceedings of the Institute of Environmental Sciences, May 11-14, 1980; Philadelphia, PA.

<u>Material</u>	<u>% Transmission ^(a)</u>		
	<u>Control</u>	<u>4 Weeks</u>	<u>8 Weeks</u>
Pyrex Glass	92	90	90
Soda Lime Glass	87	84	87
Tedlar 100BG3OUT	84	72	77
RTV 615	79	65	65
Q1-2577	74	65	64
Sylgard 184	82	81	54

(a) Direct transmission from 350 NM to 900 NM

These specimens were placed outdoors at a 45° angle and were evaluated for soil pick up after the four and eight week exposure period by optical transmission measurements. No attempt was made to clean the specimens prior to testing.

The soft surfaces of the silicone rubber resins accumulated dirt tenaciously, as expected, and lost almost 50% of the light throughput in one case (Sylgard 184). The hard and chemically resistant glass specimens retained much less dirt but still demonstrated losses of a few percent.

Based on the postulated mechanisms for soil retention on surfaces, certain characteristics of low-soiling surfaces may be assumed. These are: (a) hard, (b) smooth, (c) low in surface energy, (d) chemically clean of water soluble salts, and (e) chemically clean of sticky materials. It is possible that cost effective coatings having these properties could be applied to solar module surfaces and result in low maintenance costs and preserve the effective generation of power from these devices. A number of candidates were identified and a soiling test program was established at Springborn Laboratories, Inc.

A series of specimens for the evaluation of soil resistant surface treatments were prepared and deployed on the roof of Springborn Laboratories' facilities in Enfield, Connecticut for outdoor exposure. The specimens consisted of glass squares of 3" x 3" dimensions. Some of the squares were "Sunadex" low iron glass, the others were plain soda-lime glass used as carriers for polymeric films that had been surface treated. These organic films were held in place on the glass carriers with an adhesive.

The adhesive used for attaching the films is a non-curing solvent based pressure sensitive of acrylic chemistry. This material is produced by Uniroyal Chemical Company and designated Royal M6112. It has the features of peel strength and creep resistance at both low and high temperatures, good adhesion to glass, clear and highly transparent, high surface tack and excellent UV resistance. This adhesive was used by depositing a thin (1-3 mil) layer on glass, drying in an air oven drying in a vacuum oven and then applying the film with a press. The films trap very little air with this technique and are then treated with the anti-soiling coating directly.

The substrates under examination are "Sunadex" low iron glass, Tedlar 100BGOUT film (DuPont) and Acrylar X-22417, a biaxially oriented acrylic film produced by 3M Corporation. The surface treatments applied to these substrates are:

1. L-1668, a proprietary fluorosilane compound produced by 3M Corporation,
2. L-1668 following treatment of the surface with ozone activation (for the organic films only),
3. Dow Corning E-3820, an experimental treatment consisting of perfluorodecanoic acid coupled to a silane,
4. the E-3820 following surface treatment with ozone to create active sites on the organic polymer films,
5. Glass Resin 650, produced by Owens-Illinois,
6. SF-1000, a silicone based hardcoat resin produced by General Electric, and
7. WL-81 acrylic resin produced by Rohm and Haas.

Ozone treatments are not used with the glass because no surface activation occurs in this case.

Specimens of glass and polymers coated with the liquid glasses developed at ICI/University of Delaware are also included in the test scheme. These include soda-lime glass and acrylic panels coated with chromium phosphate, iron phosphate and titanium dioxide film.

All the completed specimens were measured for power transmission using a specially designed standard cell device, (figure 1). This instrument measures the drop in short circuit current, I_{SC} , at negligible voltage drop when the soiling specimen is placed between the cell and a light source. The degree

of soiling is assessed as the reduction in short circuit current with respect to the initial control value at zero exposure time.

A second method was also employed in the first few months of testing. This method employed a UV/visible spectrometer that had been modified to accept the mounted specimens and measure the total integrated transmission. This technique was found to result in erratic values due to specimen placement and was subsequently discontinued.

The short circuit measurements for a five month period of time are presented numerically on tables 1, 2 and 2A, and graphically in figures 2, 3 and 4. The last column of tables 1, 2 and 2A, shows the total % decrease in current determined by the fifth month only. No attempt is made to clean the specimens at any time and the surfaces used in optical measurements are never touched.

Observation of the tables shows that all the specimens, regardless of type, loose power output with exposure time and never return to original value. The Sunadex decreases the standard cell current by 3.0%, in comparison to Acrylar 22417 film, 5.6% , and Tedlar 100 film at 4.7%. The Sunadex is also the most easily improved by surface treatment. Sunadex treated with the L-1668 fluorosilane only decreased short circuit current by 0.4% at the end of the exposure period. The best values for treated Acrylar and Tedlar were decreases of 2.4% (WL-81 acrylic coating) and 1.5% (perfluorodecanoic acid treatment), respectively. In general, the fluorocarbon based treatments gave the best performance on a month to month basis. Ozone treatment of the plastic films helped to provide coupling sites for the fluorosilane primers in some cases and appeared to degrade the film in others.

Without regard for the type of treated material and individual differences, the surface treatments may be ranked according to performance in terms of average power loss, as follows:

<u>Treatment</u>	<u>Average Loss</u>
E-3820 fluorodecanoic acid primer	-1.96%
L-1668 fluorosilane	-2.56%
Ozone, L-1668	-3.2 %
Ozone, E-3820	
WL-81 acrylic coating	-3.43%
OI-650 glass resin coat	-3.56%
---None---	-4.43%
SHC-1000	-4.66%

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The ion plated and "liquid glass" coated specimens did not perform as well as the organic treatments. In addition, these treatments are all much more expensive. This series of specimens was discontinued.

Figures 2 through 4 all show the measured current values fluctuate in approximately the same pattern. This is found to correlate well with the pattern of rainfall, figure 5, and that the specimens recover some of their optical transmission from the cleaning effects of heavy rain.

In conclusion, the results of five months of outdoor exposure demonstrate that (a) Sunadex glass has the most soil resistant surface of the materials examined (b) the best treatment for Sunadex is the L-1668 fluorosilane, (c) the best treatment for the Tedlar 100 BG30UT film is E-3820, (d) the best coating for the Acrylar film to date is WL-81 coating.

These specimens will be examined at monthly intervals for the next year and any other candidate treatments that appear promising will be included in the exposure series.

IV. SUBSTRATES

Springborn Laboratories, Inc. has conducted extensive surveys into materials that may be used as cost-effective substrates for photovoltaic modules^(a). The results of these surveys suggest that the load bearing element, either substrate or superstrate will be the most expensive single component in the encapsulation package. Given the overall encapsulation cost goal of \$14.00/m² (1980 dollars), the load bearing element may amount to as much as 50% of the cost, or up to \$7.00/m².

Surveys have identified potential construction materials on the basis of the flexural strength required to meet the load deflection specifications and the cost of the material at the required thickness. The materials identified to date are as follows:

<u>Candidate Material</u>	<u>Estimated Cost</u>	
	<u>\$/ft²</u>	<u>\$/m²</u>
Hardboards (Masonite, "Super-Dorlux", Ukiah Standard Hardboard)	0.14	1.52
Strandboard (Potlatch-under develop- ment)	0.17	1.80
Glass-reinforced concrete (MBA Associates)	0.60	6.50
Mild steel (28 gauge) (base cost appx. 1¢ per sq. ft. per mil of thickness)	0.15	1.67

Mild steel is the least expensive metallic material found to date and offers the advantage of easily shaped into structures that have integral stiffening ribs incorporated into the manufactures structure. The stiffening ribs may permit the reduction of panel weight and thickness in order to meet the deflection load specifications and additionally result in a cost optimized structure.

(a) Willis, P. and Baum, B., Investigation of the Test Methods, Material Properties and Processes for Solar Cell Encapsulants, Annual Reports II and III to Jet Propulsion Laboratories, Contract 954527, July 1978 and July 1979

The difficulty with the use of mild steel is its inherent corrosion sensitivity. Modules deployed outdoors without some protection provided for the steel, will probably not last the twenty year period without rust, resulting in delamination of the encapsulated cell strings from the surface and possible mechanical deterioration of the steel structure itself. The solution to the corrosion problem depends on the form the corrosion takes. The forms of corrosion found in metals are (a) uniform attack over the exposed surface, (b) galvanic corrosion between two dissimilar metals, (c) crevice corrosion in localized shielded areas, (d) pitting corrosion and the formation of cavities, (e) intergranular corrosion at the metal grain boundaries, (f) selective leaching of metals from alloys, (g) erosion from moving solids/fluids and, (h) stress corrosion caused by the presence of a tensile stress and a corroding medium simultaneously. Probably several of these mechanisms would come into action in steel exposed to an outdoor environment.

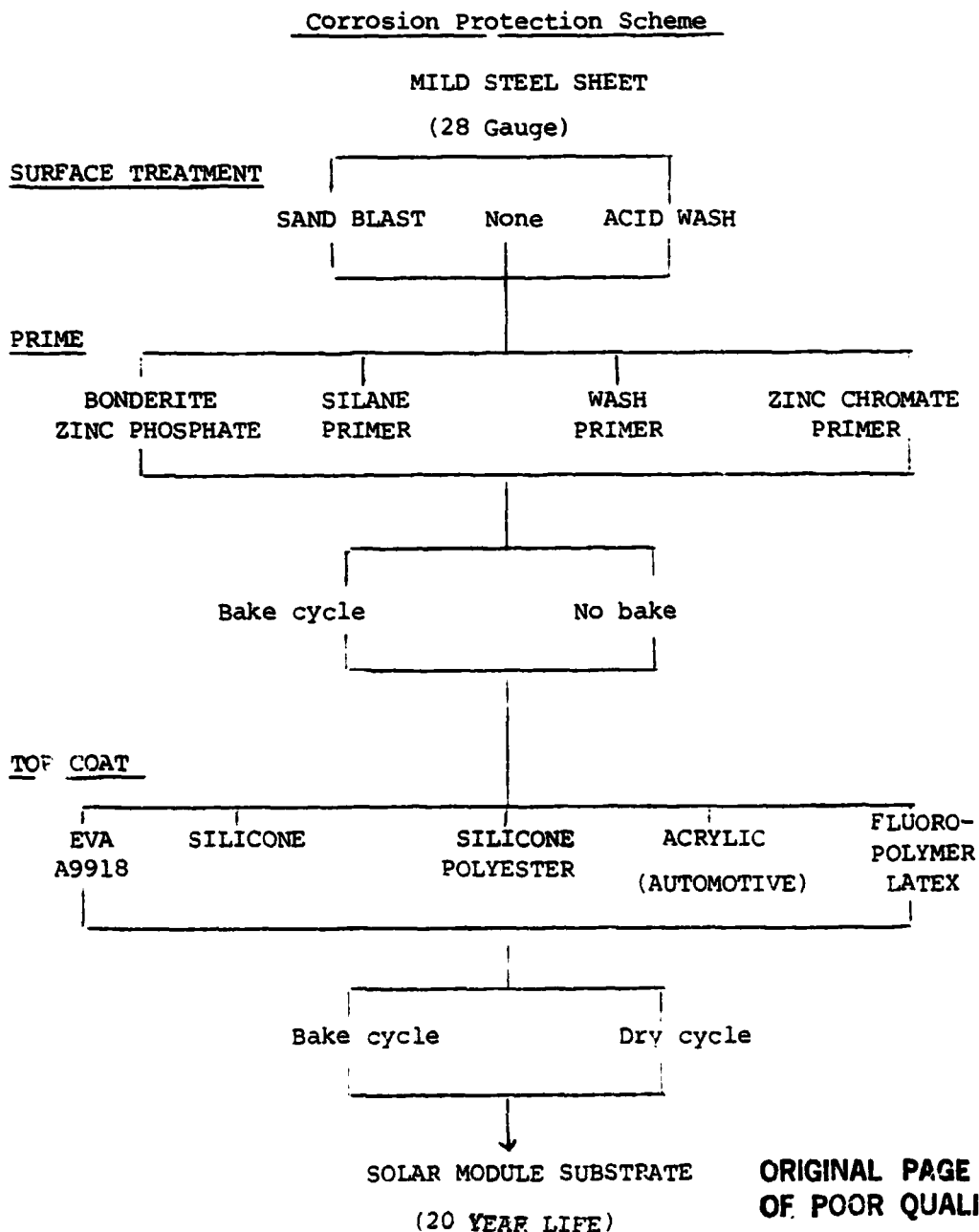
The application of protective coatings is the easiest and most obvious way of preventing the corrosion chemistry from occurring. Coatings form a barrier between the metal and its environment and isolate it from the electrolytes that are required for any of the corrosion mechanisms to occur. A good protective coating must resist acids, alkalis, salts moisture, ultraviolet light and have good adherence to metal surface for which it is intended.

Coatings may be divided into three groups; metallic, inorganic, and organic.

Metallic coatings include metal spraying, cladding, hot-dip coatings and electroplating. The least expensive metallic coatings is hot-dip galvanizing with a cost increment of about 20% over plain cold rolled mild steel. Aluminum clad rolled steel is also available, however it is almost twice as expensive (varies with grade and manufacturer).

Inorganic coating refers basically to porcelainization - a process of applying a glass frit to the surface of the steel and then firing until the glass fuses to the surface. This approach works well in terms of corrosion protection, however it is sensitive to mechanical flexing and is also expensive. The steel sheet that is suitable for porcelain enameling costs about 15% more than mild steel and the enameling process itself adds, perhaps an additional 50% to the overall cost.

Due to the ease of use, the ability to coat complex geometries, and cost benefits, our approach to the corrosion problem has emphasized the use of organic coatings. Several approaches are under consideration. The possibilities include (a) encapsulation of the entire steel substrate with the weatherable pottant compound, (b) lamination with an occlusive foil (i.e. aluminum foil) and the use of a hot melt adhesive, (c) lamination with organic films, such as pigmented polyester, and (d) combinations of these techniques. The goal is to systematically identify, assess and cost out candidate coating systems that can meet the twenty year life criterion at the lowest possible cost. The following scheme is proposed:



The type of coatings that are expected to fit into this scheme are the automotive and the maintenance coatings employed for durable siding on buildings. A brief list of possibilities follows:

Coatings ^{a.}	Cost, Both Sides ^{b.} ¢/ft ²
Polyvinylidene Fluoride (Primer + Enamel) PPG Industries, 10 years outdoor to date	11.2
Silicone/polyester Dexter-Midland, prototypes to 20 years	5.4
Polyester Dexter-Midland, 50-10 years outdoors	4.0
Acrylic Coating PPG Industries, 5 years outdoors	4.0
Polyester (Compliance Coat) Dexter-Midland, 5 years outdoors	4.0
Acrylic Emulsion Coating Dexter-Midland, 5 years (extrapolated)	5.2
Polyester Powder Coating Dexter-Midland	5.6
"Bonderite" Primer treated conversion coating; to be applied prior to coating	0.2

To date, a number of corrosion test specimens have been prepared with a variety of coatings and evaluated for performance in outdoor exposure and indoor heated salt spray (ASTM B-117) tests. These coatings are based on adhesive/film combinations and also some maintenance coatings. The results of these tests is given in Tables 3 and 4. The key for these tables is given in Table 5.

a. Recommended by industrial consultant, Mr. Milt Glaser, former Vice-President of Dexter - Midland Company.

b. The prices shown are for finished product cost, i.e., RMC and labor costs.

The salt spray condition is conducted in a closed chamber at 35°C with a continual spray of 5% salt solution sprayed on the test specimens. This condition is widely used in the plastics and coatings industries for the assessment of protective coatings, but is recognized as being a severe test. Very often, the lifetime of test specimens is measured in hours. This may be seen in the case of the mild steel control (Table 3), in which extensive corrosion is observed after only 3 hours exposure.

All the tests specimens prepared for this experiment were sealed around the edges with butyl rubber sealant tape (3M Corporation No. 5354) and an EPDM rubber gasket to form a water tight seal.

The first specimens to show a signs of attack used Acrylar acrylic film, Scotchpar polyester and aluminum foil glued to the steel with an acrylic pressure sensitive adhesive, number 4910 (3M Corporation). These specimens gave indications of change after 200 hours of exposure. The other coatings all lasted for at least 500 hours before any change was noticed, still few were found to be effective. Specimens prepared with Korad, Stainless steel, Tedlar and EVA (primed) coatings all showed sufficient attack that they were removed at or before the 2,500 hour mark.

A few of the candidate systems have survived with no signs of deterioration. The best, to date, is a combination of Scotchpar 20CP white pigmented polyester film that is bonded to the steel with EVA 9918 and the appropriate primers at the interfaces. This specimen has endured 2,500 hours with no noticable change. The other coatings that are performing well are EVA 9918 compression molded to the steel with the use of a zinc chromate modified silane primer, and a commercial fluorocarbon based topcoat from PPG Industries, Pittsburgh, Pa. with its recommended epoxy primer. These two have both reached the 2,000 hour mark with no sign of deterioration.

Other coatings under test include an acrylic based automotive enamel and a silicone modified alkyd paint. Both are surviving without change, however they have not reached the 1,500 hour mark yet. The specimens that survive the exposure period will be continued until deterioration does occur and new materials will be brought into test as they are identified.

The outdoor aging exposure (Table 4) is not nearly as severe as the salt spray condition, however the results correlated fairly well between the two conditions. Every specimen that showed no signs of attack under salt fog also showed no deterioration under outdoor weathering, and most of the specimens that did show signs of change in salt fog also changed in outdoor conditions, although to a lesser degree. Three exceptions were found; aluminum foil, Acmitite and Tedlar 200 BS30 White. Specimens prepared with these films were destroyed in salt spray but survived the 2,500 hour outdoor period with no effect. The control resulted in a light layer of corrosion within the first 200 hours and rusted badly with 500 hours.

As with the salt spray condition, the specimens will be exposed until deterioration becomes severe and new coating candidates will be added on a continuing basis. A complete economic analysis based on the flow chart previously outlined is in progress and will be presented in a subsequent report.

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V. PRIMERS AND ADHESIVES

Adhesives, primers or some other mechanism are necessary for the high reliability bonding of the assembly components to one another in order to insure the structural integrity and long life performance of the module. The adhesion between the pottant and other components, i.e., substrate, superstrate and outer cover, was investigated in the past quarter and some encouraging results were obtained with the use of primers.

A primer operates by creating a reactive chemical interface between two components, whereas an adhesive is a discreet compound that constitutes a separate phase to which the two other components may bond. Primers have been emphasized in the bonding studies due to a number of advantages they present in use. Primers are (a) used in exceedingly small quantities, (b) are cost effective, are (c) easily applied to surfaces, (d) function by the formation of high strength chemical bonds, and (e) may possibly be combined into the pottant systems to eliminate the priming step.

Tables 6 and 7 show the results of adhesion bond strength evaluations of materials and primers investigated to date. The test specimens were prepared in a manner similar to that which would be encountered in actual module fabrication. All substrate/superstrate specimens were evaluated by ASTM method D-903 for the peel or stripping strength of laminates, in which the polymer layer is pulled back off the substrate at a 180 degree angle. For flexible specimens, such as polymer bonded outer cover materials, ASTM method D-1867 ("T"-Peel) was employed. All values are reported as pounds of stress per inch of width of bond line. Specimens showing high control values were further tested after water immersion for two weeks and exposure to boiling water for periods of two hours.

The tables record the measured stress values at break, and are shown as separate tables for each of the pottants; EVA, EMA, polyurethane and butyl acrylate.

Primers that are effective for bonding EVA to almost all the other candidate surfaces have been identified, as may be seen on the chart. One extremely useful primer has recently been identified and added to the list. This primer is effective for bonding EVA to polyester film, one of the most difficult surfaces to prime. This primer, which was developed at Dow Corning, is a silane modified melamine compound which is thought to bond by forming an

interpenetrating polymer network as well as chemical bonds. The ingredients of this formulation, designated 14719 (Springborn Number), are as follows:

	<u>Parts</u>
Dow Corning Z-6040 (glycidoxypropyltrimethoxy silane)	1.25
Monsanto "Resimene 740" (melamine/formaldehyde resin)	23.75
Isopropanol, anhydrous solvent	<u>75.00</u>
	100.00

The above mixture may be further diluted with more solvent, if desired. The mixture should be kept tightly closed and free of moisture and water contamination. This primer results in extremely high strength bonds when applied to polyester film with subsequent lamination and curing with EVA. Scotchpar 20CP white polyester film, a substrate back cover candidate, was swabbed with the mixture, allowed to dry for 10 minutes at room temperature and then compression molded with EVA 9918 at 150°C for 15 minutes. The test specimens gave peel strengths of 30 pounds per inch of width and survived two hours of boiling water with a bond strength of twenty pounds per inch.

Despite the similarities in cure chemistry, EMA is much more difficult to bond than the EVA. Primer formulations effective with EVA are sometimes only marginally useful with the EMA. To date the only primer that has given good results with this pottant is All861, which gave excellent strength to Sunadex glass and good performance with mild steel.

A number of new primers were evaluated for the adhesive bonding of the aliphatic urethane and the butyl acrylate (BA) syrup pottants. Neither of these pottants have any measurable bond strength to unprimed surfaces. Z6032W primer was effective with the butyl acrylate system and Tedlar film but only marginally effective with other surfaces such as polyester or Korad acrylic film. These materials may require surface activation or a different primer system. A recommendation from Dow Corning resulted in an excellent primer for bonding the BA pottant to glass. This primer, Springborn number 14588, consists of Dow Corning Z-6020 crosslinked with a small amount of ethyl silicate to hold it to the glass surface. This primer appears to work well and gives cohesive failure to glass, even after two weeks water immersion. Exposure

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to two hours of boiling water gives a bond strength of 1.4 lbs. per inch of width, or about half the cohesive break strength. The bond strength of the butyl acrylate specimens is limited by the low tensile strength of the polymer, which appears to be approximately 3 lbs. per inch width in optimally bonded specimens.

The most recent prototype urethane formulation from Development Associates, Z-2591, was used with Dow Corning Z-6020 primer with a variety of surfaces. Marginal bond strengths were found with Korad and Tedlar but excellent bonds resulted with Sunadex low iron glass. Values in excess of 30 lbs. per inch of width were measured after the three conditions of control, boiling water immersion and room temperature water immersion. Development Associates has also recently supplied us with their own proprietary compositions, one air dry and one bake primer. These formulations were not found to be effective.

The identification of primers and/or adhesives for the high reliability of module components will continue until a recommendation can be made for each interface. Adhesion specimens will also be evaluated in a program of outdoor exposures to determine the long term weathering effects on bond stability.

VI. RS/4 ACCELERATED AGING

The degradation of polymeric materials in outdoor weathering is caused primarily by sunlight, especially the ultraviolet component. In actuality, the deteriorating effect of light is usually enhanced by the presence of oxygen, moisture, heat, abrasion, etc. and in many cases may be referred to as photooxidation, resulting from the combined effects of oxygen and sunlight.

Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 290 nm before it reaches the surface of the earth. Thus ultraviolet effects on plastic result primarily from wavelengths of approximately 290-400 nm, which constitute approximately 5 percent of the total solar radiation reaching the earth.

The lower the wavelength of light, the greater is its potential to produce a chemical change in material. This energy must first be absorbed, however. Plastics vary considerably in their ultraviolet absorbing properties, but few are completely transparent in the 290 to 400 nm range. Once the radiant energy has been absorbed, the likelihood of chemical action will depend on the degree of absorption and the stability of the chemical bonds in the polymer. The induced chemical modifications are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation and transparency.

These degradative effects may be simulated in the laboratory and accelerated to yield approximate predictions about long-term behavior from short-term testing. A number of devices are commercially available for this type of testing and include equipment such as "WeatherOmeter", "Fadometer", QUV, etc. One of the more popular and simple devices is the RS/4 exposure chamber. This device is a modification of standard test procedure ASTM D-1501, "Exposure of Plastics to Fluorescent Sunlamp", and is widely used throughout the plastics and other industries for the purpose of accelerated weathering. In this device test specimens are mounted on a turntable that rotates beneath a fluorescent sunlamp (General Electric RS/4 Type) in a closed chamber thermostated to a temperature of 50°C. The spectral output of these lamps has been determined quantitatively.^(a)

(a) Estey, Roger S., "Measurement of Carbon Arc and Sunlamp Sources at Dow Corning and Springborn Laboratories" Jet Propulsion Laboratory IOM 341-78-43, 341-78-4369.

The specimens are removed for testing at appropriate intervals based on the degradation rate of the material under examination. For the purpose of determining the relative stability of pottant and outer cover formulations, a schedule of 2 onths, 4 months and 8 months was used (1440,2880, and 5760 hours).

As a point of comparison, unstabilized polypropylene is physically degraded after approximately 160 hours and unstabilized low density polyethylene is degraded after approximately 450 hours of exposure. Outdoors, the degradation rates of these polymers varies according to their location. At Enfield, Connecticut, polypropylene with no stabilizers degrades to brittleness in approximately 8 months (5,700 hours) and low density polyethylene fails at about 18 months (12,000 hours). Areas where the sunlight is more intense, and there are fewer cloudy days, results in more rapid degradation. Exposure to higher temperatures is also significant; the degradation rate in polypropylene is almost doubled for every 10°C increase in temperature.

Due to the dependance variations in temperature and light exposure the deterioration of plastics is also location dependant. Exposures in Mexico City^(a) have been found to be about twice that of the Enfield location.

Based on these actual outdoor lifetimes, approximate correlation factors can be calculated for RS/4 to outdoor weathering. In comparing RS/4 to Mexico City, for polypropylene the acceleration factor is approximately x18 and for polyethylene approximately x13. Although these acceleration factors provide a useful basis of comparison, it should be remembered that considerable variations may be found between different outdoor locations and/or simulated weathering conditions. Factors affecting the degradation rates include specimen thickness, spectral distribution, heat history, additives, temperature, polymerization catalyst impurities, etc.

During the past two years, a continuing series of specimens have been placed under RS/4 accelerated exposure, and evaluated for mechanical or optical properties, or both, after completion of the exposure intervals indicated. The specimens under exposure have consisted of variations in EVA formulations to determine the effects of additives on the stability, samples of Korad and Tedlar outer cover films, polyurethane and EMA pottants, and an experiment with protective absorbing films over polypropylene, and specimens of opaque back cover

(a) Springborn Laboratories information resulting from a program concerning the Weathering Degradation of Polyolefins.

candidates. The results of the most recent evaluations are given in table 8, in the appendix.

The candidate pottant compounds are reviewed .st. The EVA formulation that is now commercially available, number A9918 (Springborn Formula), is surviving extremely well. After 27,000 hours of exposure the cured pottant specimen shows virtually no signs of change. The mechanical and optical properties are almost identical to control values and the physical appearance has been altered only by the accumulation of dust on the surface which results in haze. The EVA formulation in which the UV stabilizer (Cyasorb-UV-531) was replaced by a chemically reacted stabilizer (5-Vinyl tinuvin) is also surviving well, however a small drop of elongation and tensile strength is observable at the 8,600 hour exposure point. A series of three EMA formulations were evaluated. The natural uncompounded resin, EMA 2205, endured 8,600 hours of exposure but lost 85% of its elongation and was consequently removed from further testing. This effect was not surprising and actually indicates quite high stability for an uncompounded polyolefin. The fully formulated specimens, differing only by selection of peroxide curing agent (11877 and 13439), have survived 10,000 and 6,000 hours of exposure, respectively, and show no change in properties .

The two casting syrup candidates are also under exposure to determine their relative light stability. Two formulations of butyl acrylate, (cured tensile and optical test specimens) were examined, one cured with initiator alone and the other cured and formulated with stabilizing agents. The specimens have survived 8,600 hours and 5,700 hours, respectively, with no signs of degradation. The inherently high stability of this polymer is obvious from the absence of change in the unstabilized formulation. The surface texture of both these formulations is naturally tacky and is not indicative of surface degradation.

Two candidate aliphatic urethanes from Development Associates, Inc., North Kingstown, Rhode Island, were included as cast and cured tensile bars. These materials contain a proprietary stabilization system and are claimed to have good outdoor life. Both show a slight increase in tensile strength with time, probably due to residual curing reactions. The earlier formulation has survived 6,000 hours with the formation of a small amount of haze, but no deterioration of other properties. This is very good performance for an uncovered and unpigmented conventional urethane, most of which degrade within the first 1,000 hours.

Three back cover films are under exposure; Scotchpar 20CP-white, a pigmented polyester; Tedlar 200BS30W, a pigmented poly(vinyl fluoride) film; and Korad 63000, a white pigmented acrylic multipolymer. Each of these films has survived 4,300 hours of exposure with no observable signs of degradation.

Lastly, five transparent outer cover film candidates for the substrate design module are being evaluated. The most cost effective of these candidates is Acrylar film (X-22417) from 3M Corporation, ($2.25\text{¢}/\text{ft}^2/\text{mil}$ of thickness) and is a biaxially oriented acrylic film intended for outdoor applications. To date, this film has been exposed to 12,000 hours of RS/4 exposure with no major change in properties, except a decrease in strength at break. A drop in tensile strength to 50% of control value was observed after the first 1,500 hours, but this is thought to be due to stress relaxation of the polymer at the exposure temperature (50°C) and not have a bearing on the final performance of the polymer. The other candidates are types of Tedlar, with the exception of Fluorex, which is an acrylic/fluorocarbon blend. Tedlar 100BG30UT (cost appx. $5\text{¢}/\text{ft}^2/\text{mil}$), the current choice of outer cover (Springborn Laboratories), is performing very well and has survived 10,000 hours to date with no loss of properties. The other Tedlars, 4662 - a solar energy grade, and 05VT - containing chemically reacted 5-vinyl tinuvin stabilizer, are experimental materials with the potential for long life. The 05VT type is not performing well and is showing a loss of both tensile strength and elongation over the 8,600 hour test period. The 4662 grade has given some conflicting data points, but generally appears to be in good condition.

RS/4 has proven to be a useful tool for determination of the relative stabilities of polymeric materials and assessing the efficiency of stabilizing additives and other compounding approaches. The specimens currently under test will continue until signs of degradation become apparent and new compounds will be added as new candidates and formulations are identified.

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A P P E N D I X

TABLE 1
Soiling Experiments

Five Month Exposure Results: Change in Short Circuit Current, I_{sc}

Treatment	% I_{sc} Sunadex Glass(Plain)						
	0	1	2	3	4	5	Δ
None	90.5	89.0	88.7	88.7	88.8	87.8	-3.0
L-1668	89.7	89.9	88.6	88.5	89.4	89.3	-0.4
Ozone, Then L-1668	-	-	-	-	-	-	-
E-3820	90.0	89.9	89.9	88.0	88.8	88.6	-1.5
Ozone, Then E-3829	-	-	-	-	-	-	-
OI-650 Glass Resin	91.0	90.5	89.6	89.3	89.3	88.0	-3.3
SHC-1000	91.9	89.6	89.4	89.3	88.3	88.3	-3.9
WL81 Rohm & Haas	90.7	88.0	88.7	86.2	86.2	86.7	-4.4
% I_{sc} Acrylar 22417 On Glass							
None	84.0	80.9	80.7	80.3	80.3	79.3	-5.6
L-1668	80.3	79.5	80.0	78.8	77.9	77.5	-3.5
Ozone, Then L-1668	84.5	81.6	82.4	82.1	82.0	81.5	-3.6
E-3820	80.0	78.5	78.7	78.1	77.7	77.7	-2.9
Ozone, Then E-3829	84.1	83.3	82.4	82.2	82.3	82.0	-2.5
OI-650 Glass Resin	81.1	79.3	78.9	79.5	78.4	78.1	-3.7
SHC-1000	82.1	78.0	77.8	76.9	77.9	76.8	-6.4
WL-91 Rohm & Haas	83.6	81.0	80.7	82.7	81.0	81.6	-2.4

Legend: 0 = control value before exposure; referenced to standard cell
 1-5 = number on months exposure; % of original short circuit current
 Δ = % change in I_{sc}

TABLE 2
Soiling Experiments

Five Month Exposure Results: change in short circuit current, I_{sc}

Treatment	% I_{sc} Tedlar 100 BG3OUT on Glass						
	0	1	2	3	4	5	Δ
None	87.7	85.3	84.8	86.8	84.2	83.6	-4.7
L-1668	88.4	86.9	87.1	86.0	86.6	85.6	-3.8
Ozone, Then L-1668	88.1	87.4	87.3	86.2	85.9	85.6	-2.8
E-3820	86.0	86.5	86.0	83.0	85.2	84.7	-1.5
Ozone, Then E-3820	86.0	82.8	83.5	86.3	83.6	82.6	-3.9
OI-650 Glass Resin	89.0	86.3	86.4	85.3	85.5	85.0	-4.5
SHC-1000	89.0	86.5	86.9	86.3	86.4	85.7	-3.7
WL-81 Rohm & Haas	87.7	86.5	84.8	84.7	84.7	84.6	-3.5
RTV-615 Silicone	88.5	86.6	85.1	84.4	83.1	82.1	-7.2

Legend: 0 = control value before exposure; referenced to standard cell
1-5 = number on months exposure; % of original short circuit current
 Δ = % change in I_{sc}

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TABLE 2A

Anti-Soiling Treatment Evaluation
Ion Plated and "Iquid Glass" Coated Specimens

Material & Coating	Change in Short Circuit (I_{sc}) w/Standard Cell					
	0	1	2	3	4	5
Magnesium Fluoride Ion Plated Glass	88.3	87.5	86.5	86.3	85.7	85.4
Untreated Glass Blank	78.8	78.1	78.1	77.8	76.9	76.8
Chromium Phosphate Coated Glass	71.8	70.2	69.9	69.5	69.3	69.5
Iron Phosphate Coated Glass	74.9	72.8	72.7	71.7	73.7	73.5
Uncoated Acrylic Blank	90.9	90.4	89.7	88.6	89.3	87.6
Titanium Dioxide Coated Acrylic	90.5	89.3	89.5	88.2	88.2	87.2

Legend: 0 = control value before exposure; referenced to standard cell

1-5 = number on months exposure; % of original short circuit current

Δ = % change in I_{sc}

TABLE 3

Corrosion Results

Coatings on: Mild Steel Cold Rolled, 60 mil

Notebook No.	Test Specimens Materials	Adhesive/ Primer	Corrosion Conditions ASTM B-117 Salt Spray (Hours)					
			200	500	900	1500	2000	2500
14304-1	X-22417 Acrylic film	3M 4910	II, b	II, 3, c	II, 3, c	III, 4, c	R	-
14304-2	Scotchpar 20CP-white	3M 4910	II, b	II, 3, c, g	II, 3, c, g	III, 3, c, g	R	-
14304-3	1.5 mil Aluminum foil	3M 4910	II, 3, f, g	II, 3, f, g	III, 4, f, g	R	-	-
14304-4	Korad 63000 white	3M 4910	I	II, a	II, a	II, b	II, c	R
14304-5	EVA 9918	All861	I	II, 1	II, 5	III, 4	R	-
14576-6	Korad X212-R	3M 4910	I	II, 2, c	II, 2, c	III, 4, d	R	-
14576-7	Acmitite	3M 4910	I	II, e	II, e	II, e	III, 4, c	R
14576-8	Tedlar 200BS30WH	3M 4910	I	II, b	II, c	II, c	III, 4, d	R
14576-9	Stainless steel 302	3M 4910	I	II, e	II, e	II, f	III, f	R
14576-10	EVA 9918/Scotchpar 20 CPW	All861/107D	I	I	I	I	I	I
14576-11	EVA 9918/Stainless 302	All861/All861	I	II, f	II, f	II, f	III, f	R
14576-12	EVA 9918/Tedlar 100BG30	All861/107D	I	II, 2	II, 2	II, 2	III, 3	R
14576-13	Scotchclad XB-5863	None	I	II, e	II, 3, b	III, 4, c	R	-
14591-14	EVA 9918 (zinc chromate)	14590	I	I	I	I	I	-
14701-15	5MW932377 Fluorocarbon	3305 Epoxy	I	I	I	I	I	-
14713-16	Dxxtar 75X102	9X165 Epoxy	I	I	I	-	-	-
14713-17	DXD-889 Acrylic	9X165 Epoxy	I	I	I	-	-	-
14746-19H	Mild Steel, 60 mil	Control	III-R (3 hrs.)	-	-	-	-	-

TABLE 4

Corrosion Results

Coatings on: Mild Steel Cold Rolled, 60 mil

Notebook No.	Test Specimens Materials	Adhesive/ Primer	Corrosion Conditions						
			Outdoors: Enfield			Conn. (Hours)			
			200	500	900	1500	2000	2500	
14304-1	X-22417 Acrylic film	3M 4910	I	I	II,2	II,2	II,2	II,2	
14304-2	Scotchpar 20CP-white	3M 4910	I	I	II,b	II,b	II,b	II,b	
14304-3	1.5 mil Aluminum foil	3M 4910	I	I	I	I	I	I	
14304-4	Korad 63000 white	3M 4910	I	II,e	II,e,b	II,e,b	II,e,b	II,e,b	
14304-5	EVA 9918	All861	I	I	II,2	II,2	II,2	II,2	
14576-6	Korad X212-R	3M 4910	II,2	III,4	III,4	III,4,c	R	-	
14576-7	Acmitite	3M 4910	I	I	I	I	I	I	
14576-8	Tedlar 200BS30WH	3M 4910	I	I	I	I	I	I	
14576-9	Stainless steel 302	3M 4910	I	I	II,e	II,e	II,e	II,e	
14576-10	EVA 9918/Scotchpar 20 CPW	All861/107D	I	I	I	I	I	I	
14576-11	EVA 9918/Stainless 302	All861/All861	I	I	II,e	II,e	II,e	II,e	
14576-12	EVA 9918/Tedlar 100BG30	All861/107D	I	I	I	I	II,e	II,e	
14576-13	Scotchclad XB-586	6020	II,2,f	II,2,f	II,2,f	II,2,f	II,3,f	II,3,f	
14591-14	EVA 9918 (Zinc Chromate)	14590	I	I	I	I	I	-	
14701-15	5MW932377 Fluorocarbon	3305 Epoxy	I	I	I	I	I	-	
14713-16	Dextar 75X102	9X165 Epoxy	I	I	I	I	I	-	
14713-17	DXD-889 Acrylic	9X165 Epoxy	I	I	I	-	-	-	
14746-19A	Mild Steel, 60 mil	Control	II,2	III-R					

TABLE 5

Corrosion Experiments

KeySpecimen Condition

- I. No observable change
- II. Some signs of deterioration
- III. Noticable deterioration
- R. Removed from further testing:
specimen deteriorating badly

Steel Condition

- 1. Dulling of surface
- 2. Light corrosion visible (scattered spots)
- 3. Medium corrosion visible (10% of surface)
- 4. Extensive corrosion visible (over 25% of surface)

Coating Condition

- a. Blistering
- b. Slight delamination
- c. Medium delamination
- d. Complete delamination
- e. Coating discoloring, some surface attack
- f. Coating degrading/corroding
- g. Failure of sealant/gasket

TABLE 6
Adhesive Bond Strength Determination
Bond Strength by ASTM D-903 or ASTM D-1876

Notebook Number	Materials	Primer/Adhesive	Control Value lbs. per inch (ppi)	2 Weeks Water Immersion (ppi)	2 Hours Boiling Water (ppi)
Bonds to EVA A9918					
A11861-2A	Glass/EVA 9918	A11861	39.6	37.9	27.1
A11866-A	Glass/EVA 9918 w/blend	A11861	35.4	41.9	c.
A11894-3	Galvanized/EVA 9918	A11861	2.5	NT	NT
A11894-4	Mild Steel/EVA 9918	A11861	56.0	42.6	50.7
A11895-1	Aluminum/EVA 9918	A11861	41.0	2.3	2.6
A11894-1	EVA 9918/Tedlar 100BG30UT	A11861	4.5	NT	NT
A11894-2	EVA 9918/Korad 212	A11861	1.1	NT	NT
A12521-1	EVA 9918/Sunadex	A11861	34.8	Broke	32.3
A13881-1	EVA 9918/Tedlar 200BS30WH	68040	c. > 20	c.	c.
A13881-2	EVA 9918/Tedlar 200PT	68040	8.25	11.1	10.8
A13881-3	EVA 9918/Tedlar 100BG30UT	68040	6.14	tore	7.8
14316-1	EVA 9918/Scotchpar 20CP	107D	11.5	26.8	1.09
14316-3	EVA 9918/Korad 63000	107D	1.65	NT	NT
14316-4	EVA 9918/Tedlar 100BG30UT	107D	V. High	12.6	High
14316-6	EVA 918/mild steel	107D	2.26	2.28	3.07
14719-a,b,c	EVA /Scotchpar 20CP	14719	c. 35.7	c. 31.3	c. 21.3

c. Cohesive failure in pottant

TABLE 7
Adhesive Bond Strength Determination
Bond Strength by ASTM D-903 or ASTM D-1876

Bonds to EMA 13439

Notebook Number:	Materials	Primer/adhesive	Control Value lbs. per inch (psi)	2 Weeks Water Immersion (psi)	2 Hours Boiling Water (psi)
<u>Bonds to EMA 13439</u>					
A13881-4	EMA 13439/Tedlar 100BG30UT	68040	0.47	NT	NT
A13881-5	EMA 13439/Tedlar 200BS30HH	68040	1.88	NT	NT
14316-2	EMA 13439/Scotchpar 10CP	107D	0.8	0.4	1.2
14316-5	EMA 13439/Tedlar 100BG	107D	0.77	NT	NT
14316-7	EMA 13439/mild steel	11861	5.64	14.6	13.9
14316-8	EMA 13439/Sunadex	11861	60.2	40	27.7
<u>Bonds to Polyurethane Potlants</u>					
14559-0	P02-2211/Tedlar/Scotchpar	None	0	NT	NT
14559-1A	Koral/Glass	26020	4.8	2.5	0
14559-1B	P02-2211/Tedlar 100BG	26020	0.2	NT	NT
14559-1C	P02-2211/Scotchpar	26020	3.1	low	45.2
14316-9	P02-2211/Korad 63000	26020	28.0	37.2	2.5
14566-1	P02-2211/Sunadex	26020	31.4	0.6	2.7
14566-3	P02-2591/Tedlar 100BG30UT	26020	4.8	2.55	
14566-2	P02-2591/Korad 63000	26020	4.14		
<u>Bonds to Butyl Acrylate Potlants</u>					
14559-2A	BA13870/Tedlar/Korad	None	0	NT	NT
14559-2C	Scotchpar/Glass	26032W	2.35	2.35	2.27
14559-2A	BA13870/Tedlar 100BG	26032W	1.53	NT	NT
14559-2B	BA13870/Scotchpar	26032W	0.71	NT	T
14559-2B	BA13870/Korad 6300	26032W	0.90	0.36	0.59
14559-2D	BA13870/Sunadex	26032W	c. (3 0)	1.2	1.4
14588-3A	BA13870/Sunadex	14588			

c. Cohesive failure in potlants

TABLE 8

RS/4 Fluorescent Sunlamp
Exposure Results

Notebook No. Material	Exposure Hours	Specimen Condition/Testing					
		Color	Texture	%T	Modulus (100%) (psi)	Tensile (psi)	Elongation (%)
A12504-3 EVA Formula A9918 Fully compounded	2880	OK	OK	91.0	252	1930	631
	5760	OK	OK	90.5	305	1340	550
	8640	OK	OK	90	266	1460	590
	27000	OK	OK	90	258	1870	560
A12505-1 EVA + 5 Vinyl Th Formula A11873-1	2880	OK	OK	-	437	2020	595
	5760	OK	OK	-	363	1390	690
	8640	OK	OK	-	-	1570	491
A12504-2 EMA, natural Formula 2205	2880	OK	OK	90	-	250	60
	5760	OK	OK	-	-	-	-
	8640	OK	OK	-	-	272	15
A12504-1 EMA Formula A11877-fully Compounded	2880	OK	OK	-	669	2680	640
	5760	OK	OK	-	784	3240	appx. 2000
	10000	OK	OK	-	684	2620	608
13872-1 EMA 13439	2880	OK	OK	-	-	2690	623
	5760	OK	OK	-	-	2420	647

TABLE 8 -Continued 2

RS/4 Fluorescent Sunlamp

Exposure Results

Notebook No. Material	Exposure Hours	Specimen Condition/Testing					
		Color	Texture	%T	Modulus (100%) (psi)	Tensile (psi)	Elongation (%)
A13407 BA Strip No. A12805 Initiator: Vazo 33W	2880	OK	Tacky	89.0	-	22	53
	5760	OK	Tacky	-	-	134	54
	8640	OK	Tacky	89.0	-	184	62
BA 13870	2880	OK	Tacky	90	-	147	95
	5760	OK	Tacky	89.5	-	162	98
A13822 PU Z-2341	500	OK	OK	90.4	274	740	210
	1700	OK	OK	90.2	-	956	225
	2880	OK	Slt. haze	-	-	598	270
	5760	OK	Slt. haze	90.1	520	1300	255
Z-2591 Aliphatic Urethane	1440	OK	OK	90.2	-	160	123
	2160	OK	OK	90.1	-	196	143
14321-2 Scotchpar 20CP-W	2880	OK	OK	N/A	-	27400	21
	4320	OK	OK	N/A	-	28000	15
14321-3 Tedlar 200BS30W	2880	OK	OK	N/A	-	14200	63
	4320	OK	OK	N/A	-	14500	68
14321-1 Korad 63000	1440	OK	OK	N/A	-	5120	18
	2880	OK	OK	N/A	-	4950	19
	4320	OK	OK	N/A	-	4690	16

TABLE 8 -Continued 3

RS/4 Fluorescent Sunlamp

Exposure Results

Notebook No. Material	Exposure Hours	Specimen Condition/Testing				
		Color	Texture	%T	Modulus (100%)(psi)	Tensile (psi)
A12528 3M-X22417	1440	OK	OK	91	4×10^5	24000
	2880	OK	OK	91	-	13200
	5760	OK	OK	-	6.3×10^5	15000
	12000	OK	OK	91	-	14500
A12811 Tedlar 100BG30UT	2880	OK	OK	90	6×10^5	16819
	5760	OK	OK	90	2.5×10^5	16200
	9744	OK	OK	90	10×10^5	16400
A13406-1 Tedlar 05VT	2880	OK	OK	-	-	8380
	5760	OK	OK	-	-	9900
	8640	OK	OK	-	-	5440
A13406-2 Fluorex-A	2880	OK	OK	91.5	-	3790
	5760	OK	OK	91.5	-	6000
	8640	OK	OK	91.5	-	3710
A13406-3 Tedlar 4662	2880	OK	OK	-	-	14900
	5760	OK	OK	-	-	2330
	8640	OK	OK	-	-	17000

TABLE 9
Candidate Encapsulation Materials; Control Values

Mechanical Properties: ASTM D0638

Material	Optical ^a . Transmission (%T)	Instron Chart/crosshead (speed, in/min.)	Tangent ^b . Modulus (psi)	Tensile at Break (psi)	Elongation at Break (%)
PP-6523	n/a	1/1	1.9×10^5	1,910	733
PE-831	n/a	1/1	2×10^4	1,950	62
Elvax 150	90.5	10/10	850	850	1,050
EVA A9918	91.0	10/10	890	1,890	510
EMA 2205	90.0	10/10	3,200	2,080	590
EMA 11877/13439	90.5	10/10	3,240	2,000	570
PU Z-2341	90.4	10/10	611	1,160	208
PU Z-2591	90.2	10/10	254	160	115
PU AMCY 168A		10/10	4,185	5,840	651
BA 13870	89.0	5/5	90	293	110
Fluorex-A	91.5	2/2	1.4×10^5	5,560	328
Scotchpar 20CPW	n/a	5/5	3.6×10^5	29,400	27
Acrylar 22417	91.0	2/2	4.4×10^5	24,000	1
Korad 63000	n/a	2/2	2×10^5	4,250	28
Tedlar 100BG30UT	90.0	5/5	2.4×10^5	17,700	71
Tedlar 4662		5/5	2×10^5	10,600	180
Tedlar 200BS30WH	n/a	5/5	2.8×10^5	14,000	59

a. Determined with method ASTM E-424, method A, from 350 nm to 800 nm.

b. Determined by ASTM D-628 at 0.1 in/min. strain rate, modulus measured as tangent to the origin.

Figure 2

A-14

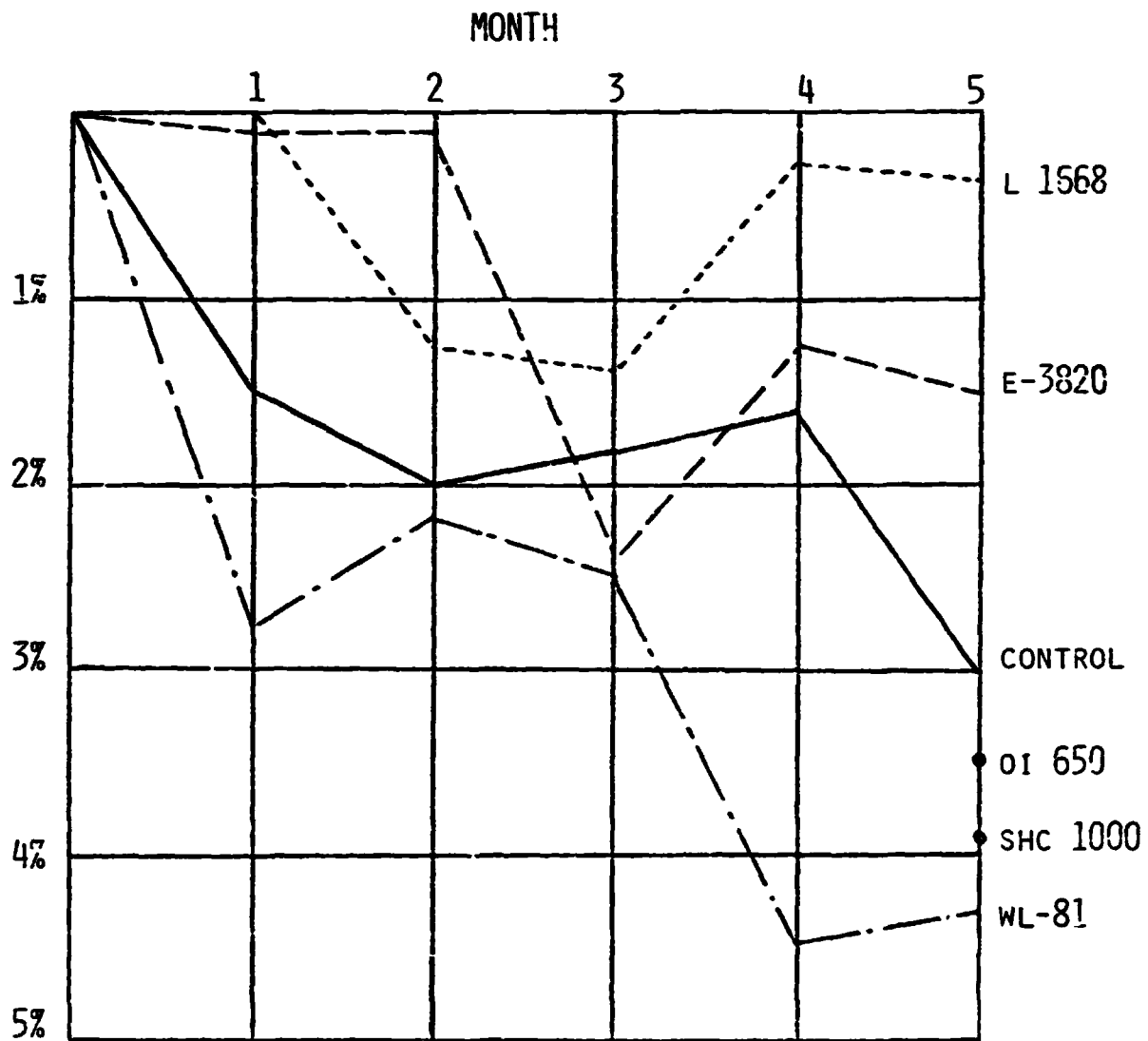
SPRINGBORN LABORATORIES, INC.

ANTI-SOILING EXPERIMENTS

FIVE MONTHS EXPOSURE, ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL

TREATED SUNADEX GLASS



BEST TREATMENT, L 1668

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Figure 3

SPRINGBORN LABORATORIES, INC.

A-15

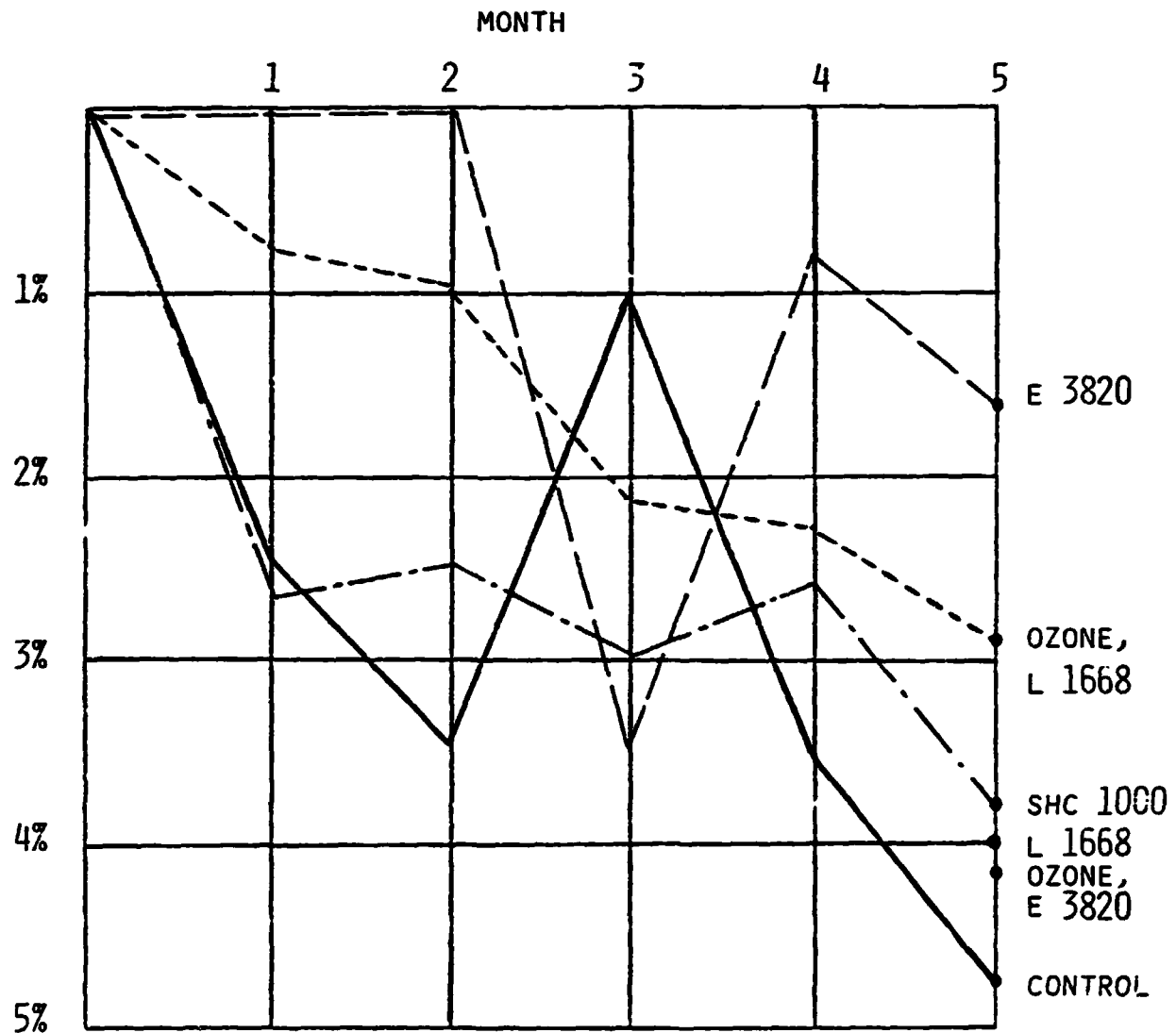
ANTI-SOILING EXPERIMENTS

FIVE MONTHS EXPOSURE, ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL

TREATED TEDLAR 100BG300UT

(SUPPORTED ON GLASS)



. BEST TREATMENT, E-3820

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Figure 4

SPRINGBORN LABORATORIES, INC.

A-16

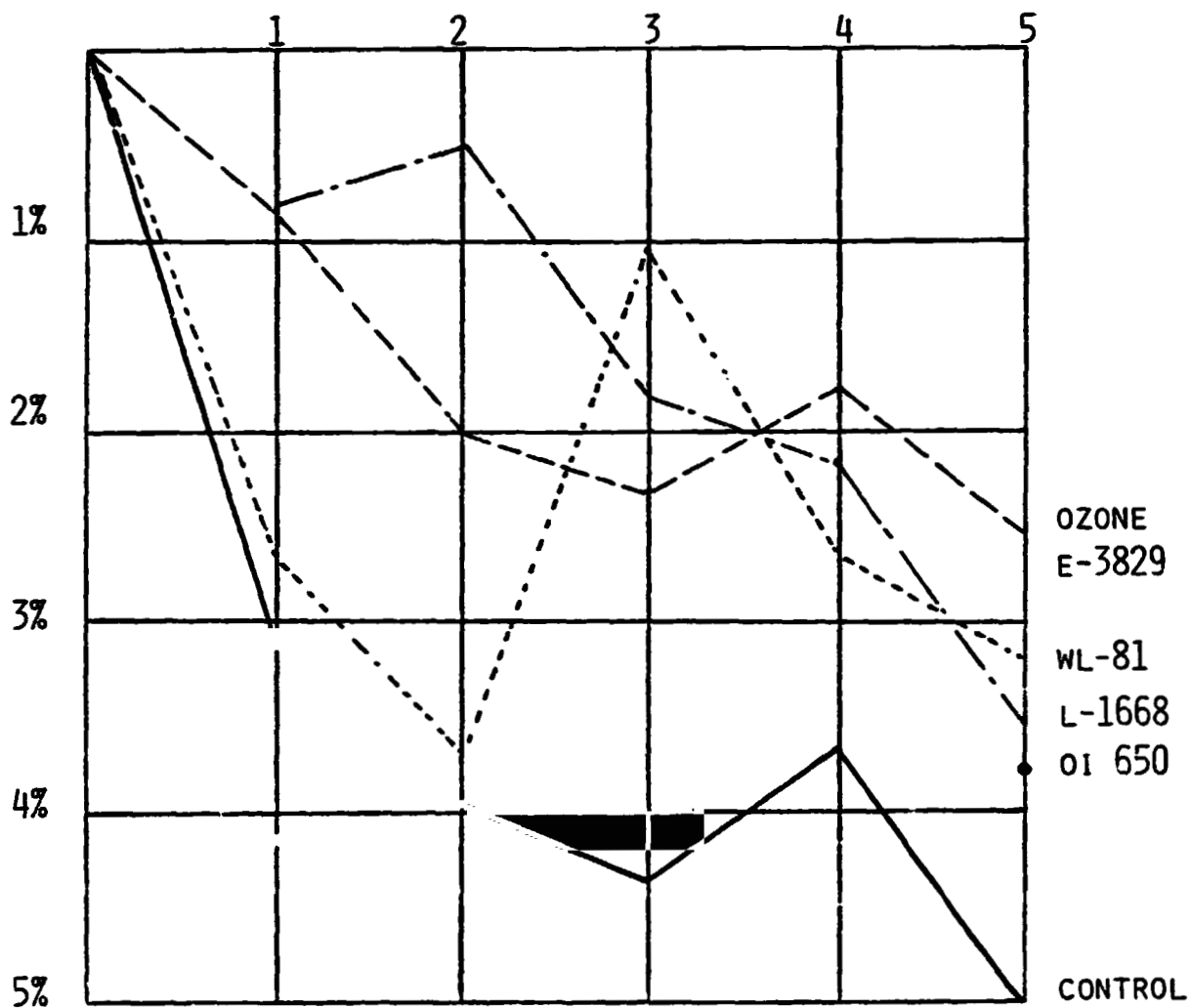
ANTI-SOILING EXPERIMENTS

FIVE MONTHS EXPOSURE, ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL

TREATED ACRYLAR
(SUPPORTED ON GLASS)

MONTH



. BEST TREATMENT, OZONE WITH
E-3829 (FLUOROSILANE)

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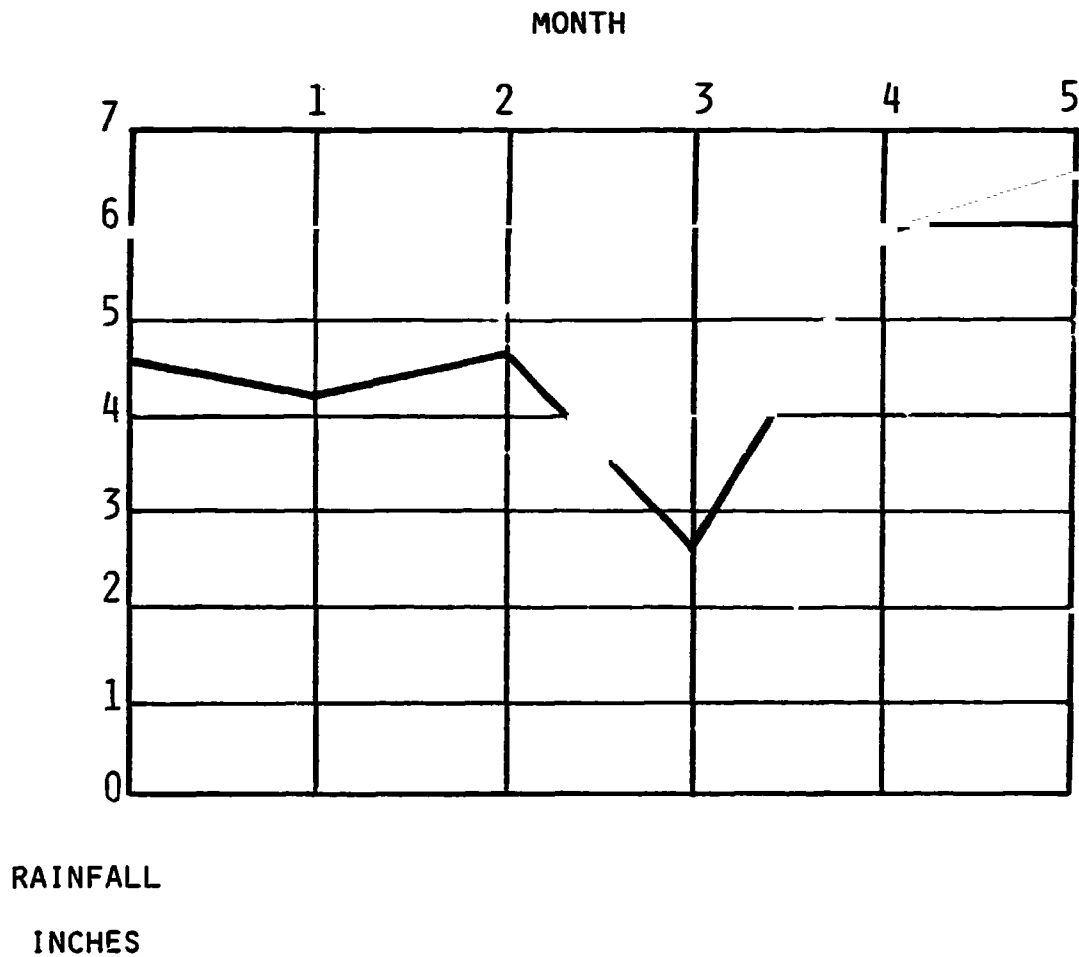
Figure 5

A-17

SPRINGBORN LABORATORIES, INC.

ANTI-SOILING EXPERIMENTS

RAINFALL CHART
FIVE MONTHS AT ENFIELD, CONNECTICUT



, THIRD MONTH LOWEST,
CORRELATES WITH HIGHEST
SOILING LEVELS

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